UNIVERSITY OF ESWATINI

FACULTY OF SCIENCE AND ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

RESIT EXAMINATION 2019/2020

TITLE OF PAPER	:	SOLID STATE ELECTRONICS
COURSE CODE	:	EEE521
TIME ALLOWED	:	THREE HOURS

USEFUL INTSRUCTIONS:

1. There are five questions in this paper, and each question is worth 25 marks. Answer any four questions in your preferred order.
2. Additional materials included in this paper are a list of useful constants, special integrals, and the periodic table.

THIS PAPER SHOULD NOT BE OPENED UNLESS OTHERWISE ADVISED TO DO SO BY THE INVIGILATOR

THIS PAPER CONSISTS OF 10 PAGES WITH COVER PAGE AND ADDITIONAL BACK PAGE INCLUDED

Question One [25 marks]

(a) Name two commonly used single-element semiconductors, and hence state the characteristic feature that they have in common. (4)

(b) Sketch the $(6\,2\,5)$ plane if the lattice constant is a. (4)

(c) Nickel has an *fcc* crystal structure with a lattice constant $a = 3.52\ \mathring{A}$. Calculate the distance between nearest-neighbor atoms in Nickel. (2)

(d) Describe the classification of solids as follows:

- (i) Crystalline (1)
- (ii) Amorphous (1)
- (iii) Polycrystalline (1)

(e) Define the following terms/phrases in relation to crystalline solids:

- (i) Lattice (1)
- (ii) Basis (1)
- (iii) Primitive cell (1)

(f) What is the difference between a semiconductor and a metal? Discuss the Fermi energy when describing the difference. (4)

(g) During Czochralski crystal growth, a Si crystal is to be pulled from the melt and doped with arsenic ($k_d = 0.3$). If the Si weighs 1 kg, deduce the number of grams of arsenic that should be introduced to achieve 10^{15} cm^{-3} doping during the initial growth. (5)

Question Three [25 marks]

(a) (i) State the Heisenberg uncertainty principle in two equations. (2)

(ii) State the meanings of the integral $\int_{-\infty}^{\infty} P(x)\mathrm{d}x = 1$ and its integrand. (2)

(b) (i) State the three postulates of quantum mechanics. (3)

(ii) The probability density distribution of a particle is given by $\rho(x) = Ax\,\mathrm{e}^{-\lambda(x-a)^2}$.

1. Calculate the normalization constant A. (5)
2. Why is it necessary to normalize the probability density distribution? (1)
3. Find the expectation value of the probability density distribution. (3)
4. Briefly describe the physical meaning of the expectation value. (2)

(c) Fig. 3.1 shows the particle in a potential well problem.

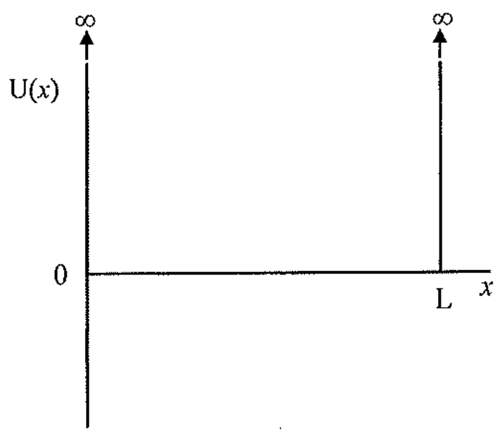

Fig. 3.1

(i) Use this diagram to deduce the Schrödinger wave equation for a free particle. (2)

(ii) Show that the particle's eigenenergy is given by $E_n = \dfrac{n^2\pi^2\hbar^2}{2mL^2}$, where all symbols have their usual meanings. (5)

Question Four [25 marks]

(a) State three uses of $p-n$ junctions. (3)

(b) In relation to the thermal oxidation of Si, write down the underlying chemical equations to:

(i) Dry oxidation. (1)

(ii) Wet oxidation. (1)

(c) Write short note on the following doping techniques:

(i) Thermal diffusion. (3)

(ii) Ion implantation. (3)

(d) Sketch and interpret the impurity concentration profile for the introduction of acceptor impurities on an originally *n*-type substrate by thermal diffusion. (5)

(e) Fig. 4.1 shows the band structure of a semiconductor.

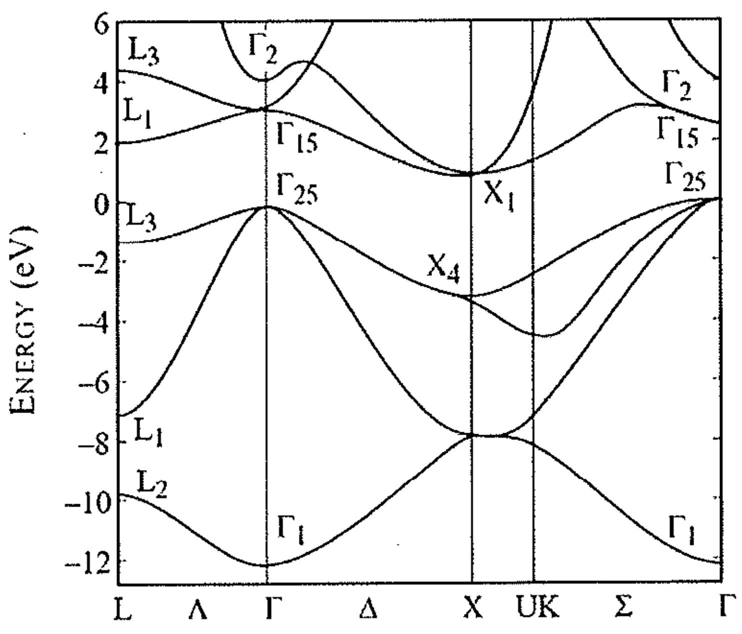

Fig. 4.1

(i) Classify this as a direct or indirect semiconductor, justifying your response. (2)

(ii) Estimate the bandgap. (1)

(iii) Explain how the effective electron mass can be determined from this diagram. (1)

(f) Draw an n-channel JFET and describe its principle of operation. (5)

Question Five [25 marks]

(a) (i) Distinguish between a JFET, MESFET, and MOSFET. (3)

(ii) Why is JFET slower than a MESFET? (1)

(iii) Draw a *p*-channel MOSFET showing the source, drain, gate, and body contacts. (5)

(b) (i) Distinguish between a BJT and FET. (2)

(ii) The base of a *pnp* bipolar transistor is grounded, and a battery is connected to bias the emitter junction. Another battery is connected between the base and the collector. This is known as the common base configuration.

1. Draw the circuit indicating the polarities of the batteries that would put the transistor in the forward active mode. Explain why you have chosen these polarities. (2)
2. Why is the emitter more heavily doped than the collector? (2)
3. How do the carriers that are emitted into the base reach the collector? (2)

(c) (i) With the aid of the I-V characteristics plot, describe how solar cell works. (5)

(ii) The depletion region of a solar cell has a certain thickness in the dark. What determines this thickness? What happens to the depletion region width when light falls on the solar cell? (1)

(iii) What limits the efficiency of a solar cell? (2)

Useful Constants and Conversion Factors, and the Periodic Table of Elements

<u>Conversion factors</u>

$1\,\text{eV} = 1.60218\times10^{-19}\ \text{J}$

<u>Physical constants</u>

Speed of light	$c = 3.00\times10^{8}\ \text{m/s}$
Planck's constant	$h = 6.63\times10^{-34}\ \text{J.s}$
Boltzmann constant	$k = 1.38\times10^{-23}\ \text{J/K}$
Electronic charge	$e = 1.602\times10^{-19}\ \text{C}$
Electron mass	$m_e = 9.11\times10^{-31}\ \text{kg}$
Proton mass	$m_p = 1.67\times10^{-27}\ \text{kg}$
Permittivity of free space	$\varepsilon_o = 8.8542\times10^{-12}\ \text{C}^2\text{N}^{-1}\text{m}^{-2}$

<u>The periodic table of elements</u>

I	II											III	IV	V	VI	VII	VIII
^{1}H 1.00																	^{2}He 4.00
^{3}Li 6.94	^{4}Be 9.01											^{5}B 10.8	^{6}C 12.0	^{7}N 14.0	^{8}O 16.0	^{9}F 19.0	^{10}Ne 20.2
^{11}Na 23.0	^{12}Mg 24.3											^{13}Al 27.0	^{14}Si 28.1	^{15}P 31.0	^{16}S 32.1	^{17}Cl 35.5	^{18}Ar 40.0
^{19}K 39.1	^{20}Ca 40.1	^{21}Sc 45.0	^{22}Ti 47.9	^{23}V 50.9	^{24}Cr 52.0	^{25}Mn 54.9	^{26}Fe 55.9	^{27}Co 58.9	^{28}Ni 58.7	^{29}Cu 63.5	^{30}Zn 65.4	^{31}Ga 69.7	^{32}Ge 72.6	^{33}As 74.9	^{34}Se 79.0	^{35}Br 79.9	^{36}Kr 83.8
^{37}Rb 85.5	^{38}Sr 87.6	^{39}Y 88.9	^{40}Zr 91.2	^{41}Nb 92.9	^{42}Mo 95.9	^{43}Tc 98.9	^{44}Ru 101	^{45}Rh 103	^{46}Pb 106	^{47}Ag 109	^{48}Cd 112	^{49}In 115	^{50}Sn 119	^{51}Sb 122	^{52}Te 128	^{53}I 127	^{54}Xe 131
^{55}Cs 133	^{56}Ba 137		^{72}Hf 178	^{73}Ta 181	^{74}W 184	^{75}Re 186	^{76}Os 190	^{77}Ir 192	^{78}Pt 195	^{79}Au 197	^{80}Hg 201	^{81}Tl 205	^{82}Pb 207	^{83}Bi 209	^{84}Po 210	^{85}At 210	^{86}Rn 222
^{87}Fr 223	^{88}Ra 226		^{104}Rf	^{105}Db	^{106}Sg	^{107}Bh	^{108}Hs	^{109}Mt	^{110}Ds	^{111}Rg	^{112}Cn	^{113}Nh	^{114}Fl	^{115}Mc	^{116}Lv	^{117}Ts	^{118}Og

Special definite and indefinite integrals

$$\int_0^1 e^{x\cdot\ln a+(1-x)\cdot\ln b}dx = \int_0^1\left(\frac{a}{b}\right)^x\cdot b\,dx = \int_0^1 a^x\cdot b^{1-x}dx = \frac{a-b}{\ln a-\ln b}\quad \text{for } a>0, b>0, a\neq b$$

$$\int_0^\infty e^{ax}dx = \frac{1}{a}\quad (a<0)$$

$$\int_0^\infty e^{-ax^2}dx = \frac{1}{2}\sqrt{\frac{\pi}{a}}\quad (a>0)$$

$$\int_{-\infty}^\infty e^{-ax^2}dx = \sqrt{\frac{\pi}{a}}\quad (a>0)$$

$$\int_{-\infty}^\infty e^{-ax^2+bx}dx = \sqrt{\frac{\pi}{a}}e^{\frac{b^2}{4a}}\quad (a>0)$$

$$\int_{-\infty}^\infty xe^{-ax^2+bx}dx = \frac{\sqrt{\pi}b}{2a^{3/2}}e^{\frac{b^2}{4a}}\quad (a>0)$$

$$\int_{-\infty}^\infty x^2e^{-ax^2+bx}dx = \frac{\sqrt{\pi}\left(2a+b^2\right)b}{8a^{7/2}}e^{\frac{b^2}{4a}}\quad (a>0)$$

$$\int_{-\infty}^\infty e^{-ax^2}e^{-2bx}dx = \sqrt{\frac{\pi}{a}}e^{\frac{b^2}{a}}\quad (a>0)$$

$$\int_{-\infty}^\infty x\,e^{-a(x-b)^2}dx = b\sqrt{\frac{\pi}{a}}$$

$$\int_{-\infty}^\infty x^2e^{-ax^2}dx = \frac{1}{2}\sqrt{\frac{\pi}{a^3}}\quad (a>0)$$

$$\int_{-\infty}^\infty e^{-\left(ax^2+bx+c\right)}dx = \frac{1}{2}\sqrt{\frac{\pi}{a}}e^{\left(\frac{b^2-4ac}{4a}\right)}$$

$$\int\sin^2 ax\,dx = \frac{x}{2}-\frac{1}{4a}\sin 2ax + C = \frac{x}{2}-\frac{1}{2a}\sin ax\cos ax + C$$